Vision Spaceport Synergy Team

Spaceport Cost Model Research Report

December, 1999

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Abstract

Vision Spaceport is a Joint Sponsored Research Agreement between NASA, industry and academia. Project members require insight into prospective space transportation system projects in order to advance the development of more affordable, safe and routine access to space. This insight should be quantifiable including such factors as costs and productivity, or flight rate capabilities. The operational phase of proposed systems is of particular emphasis. Cost information for prospective space projects is used to determine feasibility, evaluate alternatives, procure funding, and perform financial planning. The Vision Spaceport Synergy Team is developing a cost model to meet this need. This paper explores what form this model should take and presents the results of a literature search.

1 Introduction

This paper explores the problem of space project cost modeling, presents relevant information obtained by research, and provides recommendations for future development. Of particular emphasis is the area of space transportation systems operations, the recurring processes of space systems required for access to space.

1.1 Definition of the Problem

VSP customers need cost information for prospective space projects for the following reasons:

a) To provide insight into directions for investment, public or private, such as in technology
b) To determine whether a concept is financially feasible
c) To evaluate alternative concepts
d) To procure funding
e) To perform financial and schedule planning
f) To advance improvement toward achieving more routine, reliable and safe access to space

Consequently, the VSP Synergy Team is developing a spaceport concept model to meet this need [1] [2]. As described in the Cost Model Definition Document [2], the model endeavors to estimate the cost of projects at the conceptual level as well as for projects at a more defined level. Clearly, the degree of confidence should be proportional to the exactitude of problem knowledge. In any case, any model must yield a quantitative measure of its accuracy/confidence, otherwise it will amount to little more than conjecture. Of course, early model attempts may suffice to provide semi-quantitative estimates, with more accurate models to follow.

The above-defined problem is a specific instance of a more general one:

> 'How does one estimate something when the measurements and algorithms are imprecise, subjective, and conjectural?'

This classic problem recurs in diverse areas of science, engineering, and apparently finance. The degree of success will depend on just how imprecise, subjective, and conjectural the inputs are as well as the ability of the model to reflect reality.

1.2 Approach

The author is not a cost analyst and does not claim any expertise in the area. His background is Physics, and Electrical- and Systems Engineering. Consequently, he routinely applies scientific methods to engineering problems. After defining the problem, the author researched the problem by conducting a web-based search for all information relating to cost modeling, space launch-, operations-, and mission cost models, activity-based costing, parametric cost estimation, and process modeling. Advice and information was also solicited from Vision Spaceport Synergy Team members. The effort ends with the third step in the scientific method – forming a theory or hypothesis. In this context, the author interprets the results of the data collection phase and recommends what should be done next and refers the team to experts in the field.

2 Data Collection Phase

A wealth of information was found relating to space-related cost models, various cost modeling techniques, and to process modeling in general.

2.1 Space Related Cost Models

NASA and every branch of the military have developed cost models for space-related projects in all phases of a projects evolution. These phases include vehicle development, launch operations, payload development, mission operations, and long-term maintenance.

2.1.1 NASA Cost Models

NASA JSC maintains a very large collection of parametric cost models as summarized below:

Table I, NASA JSC Cost Models

http://www.jsc.nasa.gov/bu2/	Main Cost Modeling Page
http://www.jsc.nasa.gov/bu2/MOCM.html	Mission Operation Cost Model
http://www.jsc.nasa.gov/bu2/AMCM.html	Advanced Missions Cost Model
http://www.jsc.nasa.gov/bu2/ATECM.html	Aircraft Turbine Cost Model
http://www.jsc.nasa.gov/bu2/airframe.html	Airframe Cost Model
http://www.jsc.nasa.gov/bu2/CECM.html	DSN Missions Cost Analysis
http://www.jsc.nasa.gov/bu2/ELV_INTL.html	International ELV Cost Analysis
http://www.jsc.nasa.gov/bu2/ELV_US.html	U.S ELV Cost Analysis
http://www.jsc.nasa.gov/bu2/inflate.html	Inflation Calculator
http://www.jsc.nasa.gov/bu2/learn.html	Learning Curve Calculator
http://www.jsc.nasa.gov/bu2/NAFCOM.html	NASA/Air Force Cost Model
http://www.jsc.nasa.gov/bu2/SOCM/SOCM.html	Space Operations Cost Model
http://www.jsc.nasa.gov/bu2/SVLCM.html	Estimates Development and Production of Spacecraft
http://www.jsc.nasa.gov/bu2/guidelines.html	NASA JSC Costing Guidelines
http://www.jsc.nasa.gov/bu2/CERproc.html	CER Based Costing Package Parametric
http://www.jsc.nasa.gov/bu2/links.html#Companies	HUGE LIST of Cost Modeling LINKS

Table II, NASA GSFC, LRC, and ARC Cost Modeling

http://www.ksc.nasa.gov/shuttle/nexgen	Shuttle Next Generation Web Site
http://www.ksc.nasa.gov/shuttle/nexgen/AATePaperDraft.htm	Original Vision Spaceport Cost Model Technical Paper
http://joy.gsfc.nasa.gov/MSEE/cogs.htm	NASA **Operations Cost Estimation Tools GSFC**
http://joy.gsfc.nasa.gov/MSEE/msnwork.htm	NASA GSFC Mission Operations and Data Processing Workload Model
http://www.ksc.nasa.gov/shuttle/nexgen/OpsStuff	Tools Trade Study by Uwohali, Inc.
http://se-sun2.larc.nasa.gov/stae/tool_survey/tools/tol-075a.htm	NASA Langley **Requirements-Based Operations Cost Model get from JPL**
http://se-sun2.larc.nasa.gov/stae/tool_survey_a/lst-001a.htm	NASA Langley List of Tools
http://ic-www.arc.nasa.gov/ic/projects/saic/pbcm.html	NASA Ames **Process-Based Cost Model Info**
http://ic-www.arc.nasa.gov/ic/projects/saic/scea.html	NASA Ames PBCM White Paper
http://ic-www.arc.nasa.gov/ic/projects/saic/homepage.html	Links to SAIC, the company that developed many of NASA's Cost Models

2.1.2 Airforce Cost Models

The Air Force Cost Directorate maintains a large compendium of costing information and models:

Table II, Air Force Cost Models

http://www.laafb.af.mil/SMC/FM/COST.HTM	Air Force Cost Directorate
http://www.saffm.hq.af.mil/	AF Activity Based Costing Links

2.1.3 Army Cost Models

The Army maintains a large cost estimation site and provides the following:

Table III, Army Cost Models

http://www.ceac.army.mil/	Army Cost Directorate
http://www.ceac.army.mil/	Automated Cost Estimating Tool ACE-IT
http://web.deskbook.osd.mil/valhtml/1/12/122/1222/12224S01.HTM	Aircraft Sustainability Model
http://web.deskbook.osd.mil/valhtml/2/2E/2ES03.HTM	Cost Management SW for Titan LV
http://www.ceac.army.mil/	Army's List of Cost Links
http://www.anu.edu.au/mba/faculty/mlm/mlmprod.html	**Huge Center for Cost Modeling, Large list of Link**s
http://www.logsupport.com/www7.html	**HUGE ONLINE COST TOOL Catalog/Links**
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S11.HTM	**Very Interesting Life-Cycle Cost Estimation System**
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S08.HTM	**Cost-Risk Evaluator**
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S09.HTM	**Correlation Calculator for Cost-Risk Analysis**
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S10.HTM	Parametric Cost Estimating
http://web.deskbook.osd.mil/valhtml/2/25/252/252S03.HTM	Schedule Cost-Risk Analysis Module,

2.1.4 Navy Cost Models

The Navy also maintains a Cost Directorate and includes the following models and cost links:

Table IV, Navy Cost Models

http://www.navair.navy.mil/air40/air42/	NAVAL AIR Cost Department
http://www.ncca.navy.mil/links.htm	**HUGE LIST of Cost Links from NAVY**
http://www.ncca.navy.mil/products.htm	
http://www.ncca.navy.mil/research/98ABC_sel.htm	Activity Based Costing Analytical Reports
http://www.ncca.navy.mil/research/98O&S_sel.htm	Large Compendium of Military Operational and Support Phase Cost Models
http://www.ncca.navy.mil/research/98ACQ_sel.htm	Acquisition Cost Model Projects

2.1.5 DOD Cost Models

The Department of Defense Maintains a Cost Site with the following:

Table V, DOD Cost Models

http://www.dtic.mil/c3i/dodim/costool.html	**Huge List of Cost Estimation Tools *****
http://www.dtic.mil/c3i/dodim/costweb.html#Help	**DOD Cost Estimation Links**

2.1.6 Aerospace Corporation Cost Models

The Aerospace Corporation, a federally funded FFRDC, specializes in the space field and provides the following:

Table VI, Aerospace Corporation Cost Models

http://www.aero.org/software/sscm/	Small Satellite Cost Model

2.1.7 The MITRE Corporation Cost Directorate

The MITRE Corporation, also an FFRDC, has an entire division, the EDAC, devoted to supporting and guiding federal agencies such as NASA and military cost efforts. They may be found at http://www.mitre.org/resources/centers/edac.html . They are currently doing work for NASA under a contract with NOAA.

> "The Economic Decision and Analysis Center (EDAC) supports MITRE sponsors by performing cost analyses to estimate resources required to develop, procure, field, operate, and dispose of command, control, communications, intelligence, information, and space systems. The EDAC's capabilities in resource estimation cover both hardware and software cost, schedule, and staffing. Estimates are prepared by skilled analysts employing various techniques, including parametric, analogy, and activity based costing, as well as engineering techniques. Many cost models are available within the Center. By working closely with sponsors and technical teams, EDAC helps provide an understanding of cost drivers and tradeoff issues at critical program decision points. Typical Center products include system and program cost and schedule estimates, economic analyses, Analysis of Alternatives (AOAs), cost/benefit analyses, and functional economic analyses."

Assessments of cost and schedule risk associated with the estimates and analyses accompany all the Center's products.

2.1.7.1 Telecon with MITRE's Economic and Decision Analysis Technical Center (EDAC)

On November 10, 1999 Vision Spaceport Synergy Team members held a telecon with Ms. Diane Buell Principal Space Systems Engineer, and her MITRE colleagues [5]. Attending were Edgar Zapata, Russell Rhodes, Mike Sklar and myself. The meeting confirmed MITRE's interest and expertise in both Space Systems costing as well as Large Systems Costing and costing theory. After forwarding the JSA documentation to MITRE, Ms. Buell sent us an email stating that she and her colleagues are looking into possible VSP collaboration and that Mr. Jim Bui has talked to a NASA/Marshall engineer interested in helping us with model validation. Mr. Bui went on to say that Ms. Arlene Moore of NASA/Langley is heading up a NASA-wide IPT dealing with launch and mission costing and that Langley may have the resources to bring to bear, and may conceivably be in a position to utilize MITRE also.

2.1.8 Commercially Available Space-Related Cost Models

A number of private companies also provide space-related cost models and tools as summarized below:

Table VII, Commercially Available Cost Models

http://www.silcom.com/~technomi/cost_models.htm	**SPACE, Aircraft, Communication, Sensor Costing from TECHNOMICS, Inc.**
http://www.tecolote.com/products/models.htm	**SPACE related costing from Telocote, Inc.**

2.2 Information on Cost Modeling and Related COTS Tools

Information was obtained on Parametric Cost Modeling, Activity-Based Costing, Analogy-Based Costing, and unique cost approaches.

2.2.1 Parametric Cost Modeling Links

The JSC Parametric Cost Estimating Handbook describes Parametric Cost Estimation as follows:

> "A parametric cost estimate is one that uses Cost Estimating Relationships (CERs) and associated mathematical algorithms (or logic) to establish cost estimates. For example, detailed cost estimates for manufacturing and test of an end item (for instance, a hardware assembly) can be developed using very precise Industrial Engineering standards and analysis. Performed in this manner, the cost estimating process is laborious and time consuming. However, if history has demonstrated that test (as the dependent variance) has normally been valued at about 25% of the manufacturing value (the independent variable), then a detailed test estimate need not be performed and can simply be computed at the 25% (CER) level. It is important, though, that any CERs used be carefully tested for validity using standard statistical approaches."

Table VIII, Parametric Costing Links

http://infinity.msfc.nasa.gov/Public/pp01/pp03/history.html	History of NASA Cost Modeling Attempts
http://mijuno.larc.nasa.gov/dfc/biblio/pcab.html	Parametric Cost Analysis Bibliography
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S10.HTM	Parametric Cost Estimating
http://www.jsc.nasa.gov/bu2/PCEHHTML/pceh.htm	NASA JSC Parametric Cost Estimating Handbook
http://ic-www.arc.nasa.gov/ic/projects/saic/scea.html	NASA ARC Paper on Parametric Cost Estimation
http://www.ispa-cost.org/pceinewsletters/pnews4.htm	GE Parametric Cost Estimating Newsletter
http://www.jsc.nasa.gov/bu2/resources.html#software	JSC Links to Cost Estimating Software, Books, Periodicals
http://www.ispa-cost.org/	International Society of Parametric Analysts
http://www.contract.org/parametrics.htm	Parametric Cost Estimating Initiative

2.2.2 Activity Based Costing Links

Chris Pieper of ABC University describes Activity-Based Costing as follows:

> "Activity-Based Costing (ABC) was developed as a practical solution for problems associated with traditional cost management systems. In the early 1980's many companies began to realize that their traditional accounting systems were generating inaccurate costing information. Traditional cost accounting systems that were designed to address the issues of inventory valuation for external audiences have two deficiencies:
>
> 1.the inability to accurately determine actual total product and service costs
>
> 2.the inability to provide useful information to management for purposes of making operating decisions
>
> As a result, managers of companies selling multiple products and services were making decisions about pricing, product mix, and technology based on inaccurate cost information.
>
> Alternatively, ABC focuses on the activities associated with operating the business. Traditional cost systems do not touch the subject except in reports that isolate salaries, benefits etc. If a manager were asked to cut costs, he or she would cut headcount believing that it is the only largest cost contributor. But, today, people are not the major cost contributors; activities that people do contribute more. How often have we heard the lament well, we've cut our staff 20% but the work is still here. ABC allows managers to attribute costs to activities and products much more accurately than conventional accounting methods. ABC is more than an accounting tool. These tools give you a view of what you have done financially and are fundamental to shareholding disclosure and the statutory reporting. But it is as important to have the ability to translate this cost information to the language of operational units and the business. With ABC, you get a strong internal view of your products/services and customers. Armed with this information, you are ready to make financial, operational and strategic decisions such as outsourcing and pricing.
>
> ABC identifies the activities that are responsible for costs. Activity costs are passed on to products or services only if the product or service uses the activity, i.e. activities consume resources, and products/services consume activities. As the number of activity measures increase, ABC is better able to capture the underlying economics of the company's operations, and the reported activity/product/service costs come to light. In addition, ABC analyzes all activities exist to support production and deliver of goods and services."

Table IX, Activity Based Costing Links

http://www.abctech.com/	**ABC University** – Huge Authority on Activity Based Costing and Cost Models
http://www.pitt.edu/~roztocki/abc/abctutor/	ABC Tutorial
http://akao.larc.nasa.gov/dfc/abc.html	NASA Paper on Activity Based Cost Modeling
http://www.ml.afrl.af.mil/successes/1998/ss98077.html	Air Force Activity-Based Costing Reports
http://www.saffm.hq.af.mil/	AF Activity Based Costing Links
http://www.ml.afrl.af.mil/successes/1998/ss98077.html	AF Activity-Based Success Stories
http://www.ncca.navy.mil/research/98ABC_sel.htm	Navy Activity Based Costing Analytical Reports
http://www.rutgers.edu/Accounting/raw/ima/imabc.htm	Implementing Activity Based Costing
http://www.rutgers.edu/Accounting/raw/ima/imabc3.htm#bi	ABC Bibliography
http://solutions.sun.com/catalogs/all/Business_Related/Government/33425.html	Activity Based Costing **Software**
http://www.sapling.com/	Activity Based Management **Tools** NetProphet
http://www.acornsys.com/	Activity Based Costing COST **Software**
http://www.abctech.com/software/prdserv1.htm	OROS 99 Activity Based Costing **COTS Package**

Table IX, Activity Based Costing Links (Continued)

http://www.pitt.edu/~roztocki/abceva/index.htm	**Univ. of Pittsburgh ABC and ABC/EVA !EXCELLENT TREATMENT and LIST OF ABC and EVA Links**
http://www.pitt.edu/~roztocki/abcmyths	**Presentation on Myths about ABC**
http://www.newpaltz.edu/~roztockn/abcpaper.htm	**Implementing ABC**
http://mijuno.larc.nasa.gov/dfc/abc/abcbib.html	**Annotated Bibliography on ABC from LARC**
http://mijuno.larc.nasa.gov/dfc/biblio/abcbiblio.html	Ed Dean's ABC Bibliography
http://www.acq-ref.navy.mil/wcp/abc2.html	**Navy Paper on Implemting ABC**
http://mime1.marc.gatech.edu/Courseware/autorecycling/ABC.html	**Tutorial grom Ga Tech Also has ABC With FUZZY Logic to handle UNCERTAINTY!!!!**
http://www.nan.shh.fi/raw/ima/imabc.htm	**Paper on IMPLEMENTING ABC**
http://www.faa.gov/ait/bpi/handbook/chap5.htm	**ABC Costing Organizational Act from FAA**
http://www.cfoeurope.com/199810f.html	**Critique of Activity Based Costing NOT as Easy as ABC!!!**
http://www.rutgers.edu/Accounting/raw/ima/imabc.htm.	**Practices and Techniques Implementing ABC, Rutgers Univ**
http://www.abctech.com/library/library.htm#whitepapers	**HUGE Compendium of ABC Papers**
http://www.leadsoftware.com	**LEAD Software, ABC COTS Tools**
http://www.acornsys.com	**Acorn Systems, ABC COTS Tools**
http://www.armstronglaing.com/solad.htm	**Armstrong Liang Co., ABC COTS Software and Process Mapping Tools**

2.2.3 Analogy-Based Costing Links

The basis of estimation by analogy is to characterize (in terms of a number of variables) the project for which the estimate is to be made and then to use this characterization to find other similar projects that have already been completed. The known effort values for these completed projects can then be utilized to construct an estimate for the new project.

Table X, Analogy-Based Costing Links

http://www.estec.esa.nl/eawww/ecom/analogy/analogy.htm	**Euro Space Agency, Cost Estimation by Analogy Page**
http://www.cs.jmu.edu/users/foxcj/cs555/Unit3/PrjPlan/sld009.htm	*Cost Estimation by Analogy Tutorial*
http://web.nps.navy.mil/~drmi/chapter3.htm	Parametric and Analogy/Engineering based
http://dec.bournemouth.ac.uk/dec_ind/decind22/web/Angel.html	Software Cost Estimation by Analogy, ANGEL Project
http://dec.bournemouth.ac.uk/dec_ind/decind22/web/ESCOM96.html	Software Cost Estimation by Analogy,
http://dec.bournemouth.ac.uk/dec_ind/decind22/web/ESCOM95.html	More on ANGEL Project
http://dec.bournemouth.ac.uk/dec_ind/decind22/web/ESCOM95.html	Online paper: Software Support for Cost Estimation by Analogy
http://dec.bournemouth.ac.uk/dec_ind/decind22/web/ESCOM96.html	Effort Estimation by Analogy: A Case Study

2.2.4 Unique Cost Modeling Links

Table XI, Unique Cost Modeling Links

http://www.dgsciences.com/bipsa/bpsa7n16.htm	**Neural Net Cost Estimator when** information is scant or conceptual
http://solutions.sun.com/catalogs/all/Manufacturing/Manufacturing_Resource_Planning/36593.html	**MetCAPP Knowledge-Based** Process and Cost Estimating System
http://www.vtt.fi/cic/projects/combine2/cetl1.htm	**COMBINE 2, Costing Tools** – includes Neural Net, user interface Visual Basic. Used for Early Planning Phases
http://www.ecfc.u-net.com/cost/machine.htm	**Machine Learning Cost Estimators**
http://www.ecfc.u-net.com/cost/neural.htm	**Neural Net Cost Estimators**
http://www.ecfc.u-net.com/cost/fuzzy.htm	**Fuzzy Logic Cost Estimators**
http://www.ecfc.u-net.com/cost/case.htm	**Case-Based Reasoning Cost Estimators**
http://www.ecfc.u-net.com/cost/analogy.htm	**Analogy-Based Cost Estimators**
http://www.ecfc.u-net.com/cost/rule.htm	**Rule-Based Cost Estimators**
http://www.ecfc.u-net.com/cost/trees.htm	**Regression Tree-Based Cost Estimators**
http://www.ecfc.u-net.com/cost/hybrid.htm	**Hybrid Neuro-Fuzzy Cost Estimators**

2.2.5 COTS Cost Tools

Numerous Commercial-Off-the-Shelf cost tools were found, many listed under Sun Microsystem's Solutions Catalog:

Table XII, COTS Cost Tools

http://www.jsc.nasa.gov/bu2/links.html#Companies	NASA JSC's List of Cost-Related Companies
http://www.decisioneering.com/crystal_ball/index.h	Crystal Ball Risk Analysis/Sim COTS
http://www.estimatingsystems.com/	PULSAR Construction Cost Estimating Tools
http://www.galorath.com/main_frame.html	SEER COTS Tool
http://www.galorath.com/estimating_frame.html	Software Estimating Tools
http://www.costimator.com/	Manufacturing Technologies, Inc. RapidCOST,
http://www.microest.com/index.htm	Micro Estimating Systems , Inc. Fabrication and
http://www.modtechcorp.com/1.0/1.0.cfm	Modern Technologies Corporation, cost analysis
http://www.ontrackengineering.com/ontrack.shtml	**CostTrack Project Management COTS**
http://www.palisade.com/	**Excellent Suite of Tools including @Risk**
http://www.psindustry.com/frameset.html	**Manufacturing Cost Planning**
http://www.resi.net/html3/winrace30.html	
http://www.silcom.com/~technomi/cost_models.ht	**SPACE, Aircraft, Communication, Sensor**
http://www.leadsoftware.com	**LEAD Software, ABC COTS Tools**
http://www.acornsys.com	**Acorn Systems, ABC COTS Tools**
http://www.armstronglaing.com/solad.htm	**Armstrong Liang Co., ABC COTS Software and**
http://www.tecolote.com/products/models.htm	**SPACE related cost models**
http://www.timberline.com/prec.htm	Construction Cost Modeling
http://www.uscost.com/August.htm	Construction Cost Modeling
http://www.vertigraph.com/	
http://www.walker.com/products_services/	Construction Cost Modeling
http://www.winest.com/	

2.3 Process Modeling and Related COTS Tools

All space projects involve sequences of activities, some of which are complex, involve large teams, and exhibit dependencies. These activities constitute processes involving engineering, manufacturing, launch operations, mission operations, test and checkout, payload integration, and post mission analysis and data reduction. Clearly, the better the knowledge of the processes, the better the ability to estimate costs related to such activities. This is especially true for activity-based cost approaches. Consequently, the ability to pictorially capture the process and annotate/populate a database with cost related info will help the cost estimation process. A number of COTS tools for process modeling are currently available, some of which have interfaces/components to Cost Estimation COTS Tools. They are summarized below:

Table XIII, Process Modeling and Related COTS Tools

http://www.ismodeler.com/index.html	**ISModeler** Process Modeling and Activity Based Costing COTS
http://www.simulationdynamics.com/index.html	Simulation Dynamics Process/Cost Modeling COTS
http://solutions.sun.com/catalogs/all/Business_Related/Vertical/17997.html	Process Modeling and Visualization Tool
http://solutions.sun.com/catalogs/all/Business_Related/Vertical/36763.html	What If Business Modeling SW
http://www.cs.man.ac.uk/ipg/	Information Industry Process Modeling University of Manchester
http://www.cs.man.ac.uk/ipg/pelsiam.html	Legacy Process Engineering Tool Univ. of Manchester
http://www.cs.man.ac.uk/ipg/pie/pie-e.html	Process Instance Evolution Univ. of Manchester
http://www.elet.polimi.it/section/compeng/db/wf/	Workflow Management Modeling Milan Polytechnica University, including: Modeling of Unexpected Exceptions and a sophisticated Database to Support Workflow Management, Interoperability and Inter-Departmental Workflow
http://www.comp.lancs.ac.uk/computing/research/cseg/	Cooperative Engineering, University of Lancaster:
http://www.ie.utoronto.ca/EIL/eil.html	University of Toronto: Industrial Engineering – Enterprise Integration Laboratory include Supply Chain Management
http://www.dms.csiro.au/world/ProgC/mmip/	Mathematical Modeling of Industrial Processes
http://bprc.warwick.ac.uk/bp-site.html#SEC4	Process Reengineering: Research, Tools, Practice
http://www.cimpact.ch/Faq.html	Process Model
http://solutions.sun.com/catalogs/all/Manufacturing/Manufacturing_Resource_Planning/38990.html	CS/2 Processing, Workflow, and Costing SW
http://solutions.sun.com/catalogs/all/Manufacturing/Manufacturing_Resource_Planning/24710.html	**Logility** Manufacturing Planning SW
http://solutions.sun.com/catalogs/all/Manufacturing/Manufacturing_Resource_Planning/36593.html	**MetCAPP** Knowledge-Based Process and Cost Estimating System
http://www.gensym.com/	Process Modeling

http://www.kbsi.com/	Process Modeling , Knowledge Based Systems, Inc.
http://www.hyperion.com/solutions.cfm	Sapling Cost Modeling Software
http://www.kbsi.com/Services/R&d.htm	Activity-Based Costing, Knowledge Based Systems, Inc.
http://www.processmodel.com/Products/Overview/overview.html	ProcessModel, Inc.
http://www.processmodel.com/	ProcessModel
http://www.metasoftware.com/products.html	Workflow Analyzer from Meta Software
http://www.proformacorp.com/	Business Process Re-engineering, Proforma Corporation

2.4 Quality Function Deployment

Cost deployment is one facet of a holistic quality-based approach that treats quality, technology, cost, and reliability throughout the product life cycle. This approach allows the natural synergy amongst these facets to drive a rational product life cycle. Numerous Quality Function Deployment related web sites have been found, some of which focus on Cost Deployment/Estimation. They are summarized below:

Table XIV, Quality Function Deployment Links

http://mijuno.larc.nasa.gov/dfc/qrd/cqfd.html	Edwin Dean's treatment of CQFD and QFD
http://dfca.larc.nasa.gov	Edwin Dean's Design for Competitive Advantage Page
http://mijuno.larc.nasa.gov/dfc/qfd/qfdbib/cstdepb.html	Cost Deployment
http://mijuno.larc.nasa.gov/dfc/biblio/tcab.html	Edwin Dean's Theoretical Cost Analysis Bibl.
http://dfca.larc.nasa.gov/dfc/ctec.html	Edwin Dean's Design for Comp. Advantage Cost Page
http://sscag.saic.com	**SPACE SYSTEMS COST ANALYSIS** Group VSP SHOULD JOIN!!
http://www.dnh.mv.net:80/ipusers/rm/qfd.htm	QFD Page
http://box.ikp.liu.se/research/project/QFD.html	QFD at Linkoping University

2.5 Risk Assessment and Mitigation

No cost model would be complete without a treatment of risk and uncertainty. After all, not all development efforts follow a completely benign path – unexpected failures or situations can and do occur. The cost model should be sophisticated enough to allow for these paths and give confidence intervals associated with them. A large compendium of academic, government, and commercial reports are available as follows:

Table XV, NASA Risk Assessment and Mitigation Links

http://www.decisioneering.com/crystal_ball/index.html	**Crystal Ball** Risk Analysis/Sim COTS
http://www.palisade.com/	**Excellent Suite of Tools including @Risk**
http://web.deskbook.osd.mil/valhtml/2/25/252/252S03.HTM	Schedule Cost-Risk Analysis Module,
http://www.elet.polimi.it/section/compeng/db/wf/	Workflow Management Modeling Milan Polytechnica University, including**: Modeling of Unexpected Exceptions** and a sophisticated Database to Support Workflow Management, Interoperability and Inter-Departmental Workflow
http://www.cs.man.ac.uk/ipg/	Information Industry Process Modeling University of Manchester
http://www.cs.man.ac.uk/ipg/pelsiam.html	Legacy Process Engineering Tool Univ. of Manchester
http://www.cs.man.ac.uk/ipg/pie/pie-e.html	Process Instance Evolution Univ. of Manchester
http://www.ie.utoronto.ca/EIL/eil.html	University of Toronto: Industrial Engineering – Enterprise Integration Laboratory include Supply Chain Management
http://www.dms.csiro.au/world/ProgC/mmip/	Mathematical Modeling of Industrial Processes
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S08.HTM	**Cost-Risk Evaluator**
http://web.deskbook.osd.mil/valhtml/2/2B/2B4/2B4S09.HTM	**Correlation Calculator for Cost-Risk Analysis**

2.6 TRANSCOST Model

The TRANSCOST Model for Space Transportation Systems Cost Estimation and Economic Optimization [6] covers all three areas of cost assessment:

Development Cost
Vehicle Recurring Cost
Flight Operations Cost

The Development Cost- and Vehicle Recurring Cost submodels are again subdivided into models for the following technologies:

Liquid Rocket Engines
Solid Rocket Boosters
Expendable Ballistic Rocket Stages
Unmanned Reusable Ballistic Vehicles/Stages
Winged Orbital Reusable Vehicles
Advanced Aircraft/Winged First Stage Vehicles

TRANSCOST is a system-level model, and is based on actual costs of completed projects with careful data evaluation and use of sophisticated statistical methods. Consequently, a number of specific Cost Estimation Relationships (CERs) have been derived. Many of the CERs are based on vehicle or vehicle component mass and have the basic form of:

$$C = a * M^x$$

Where C = cost, a = a system-specific constant value, M = mass in kg, and x = a system specific cost/mass sensitivity factor. The CERs are derived from historical space projects and application of error minimization techniques and outlier mitigation and special consideration to 'first of a kind' projects. The submodel CER computations also utilize 'f-factors' that take into consideration:

Development Standard
- First Generation/State-of-the-art System
- New Design Using Either Existing Components or Similar to Existing Systems
- Variation of Existing Design, with Minor Modifications

Technical Quality Factor
- Element-specific Correction Factor
- Related to Level of Technical Advancement
- Related to Reliability/Safety/Maintainability Demands

Team Experience Factor
- Function of Team Experience with a Given Technology and Project

Learning Factor
- Cost Reduction Achieved when Producing a Series of Similar Projects/Vehicles

Dr. Koelle's models appear to reliably estimate some development- and recurring costs of historical projects to within 15-50%. The newest submodel, the Flight Operations Cost Submodel, is still in development.

TRANSCOST Flight Operations Cost Submodel is of particular interest because the Vision Spaceport Cost Model currently focuses on twelve launch/operations modules [1][2]. The Flight Operations Cost Model is comprises the following components:

- Direct Operations Cost
  - Includes management, prelaunch operations (assembly, checkout), launch operations and mission control, propellants, and ground transportation.

- Refurbishment and Maintenance Costs
  - All effort preceeding the pre-launch operations to bring the vehicle to the same status as a newly-buildt system.
    - Includes the cost of all required spares and manpower for maintenance.

- Indirect Operations Cost
  - Program Administration
  - Launch Site Management, Facilities Maintenance, Spares, Storage and Supply Service
  - Engineering Support, Vehicle Improvements
  - Fees and Profit, Reserve Fund Contributions, etc.

- Additional Costs (for commercial projects)
  - Vehicle Cost Amortization
  - Development Cost Amortization

The operations costs are sensitive to the size and complexity of the vehicle (especially whether it is manned or unmanned), the assembly and launch mode, the propellant cost, transportation and recovery mode, the number of reusable elements and their refurbishment factors, the number of launches per year, and indirect operations costs.

According to Dr. Koelle's data, the Flight Operations Cost Submodel appears to account for the dominant cost drivers for historical projects.

Table XVI, TRANSCOST Related References

TRANSCOST, Statistic-Analytical Model for Cost Estimation and Economic Optimization of Space Transportation Systems	**MBB-Report No. URV-180(88)** **Author: Dietrich Koelle**
Future Low Cost Space Transportation System Analysis	**Acta Astronautica, Vol 6 (1979), pp 1635-1668Euro Space Agency, Cost Estimation by Analogy Page,** **Authors: Dietrich Koelle, H. H. Koelle**

2.6 Air Transport Association (ATA) System Code Approach

The Air Transport Association has devised a common set of aircraft-related accounting codes. The codes are organized according to industry-accepted categories including ones for aircraft systems, subsystems, and components. Use of these standard codes provides an open systems advantage and allows different groups, companies, and organizations to share information and solutions. In particular, a number of third-party aircraft/airline accounting packages and cost simulation systems exist that utilize this standard.

Bryant Aumack of the USA Corporation, formerly of Eastern Airlines, has done significant work streamlining and automating Eastern's accounting and tracking system based on the ATA systems approach [4]. He also completed a research effort to convert Shuttle accounting to an ATA-compliant breakdown. Such a cost breakdown would allow a more precise and detailed set of costs inputs to our cost model. It would also allow the Shuttle world to utilize existing cost estimators, at least for those Shuttle elements mappable to existing aircraft. Mr. Aumack noted that a number of Shuttle systems are analogous to commercial aircraft and that some existing models could probably be tuned to our special requirements. For comparison purposes, the Shuttle could be ranked between a Boeing 757 and a DC-10.

Use of ATA codes would go a long way in solving the "lack of data" problem (described by Zapata and Torres [1]):

> *"The lack of hard data, such as maintainability parameters, cost data down to sub-systems (main propulsion, power, controls, etc) and most reliability/dependability data has severely hampered the state of operations cost modeling for future reusable space transportation systems. That the Shuttle fleet is the only semi-reusable, operational, crew capable, access to space makes the situation even more severe.*
>
> *This undesirable situation, affecting understanding the operation of reusable space transportation systems, has not gone without notice by multiple parties throughout the years"*

Another side-benefit of ATA-compliance would be the addition of several alternative cost models for the Shuttle. These models and the Vision Spaceport Model could be fit into the Binary Polling Scenario Architecture approach to yield better results than any model alone. This approach is analogous to the impressive results in hurricane prediction that FSU achieved using similar methods.

Table XVII, ATA Systems Codes and Approach Links

http://www.air-transport.org/public/publications/61.asp	**SPEC 2000: Integrated Data Processing Materiels Management (Main Document & Common Support Data Dictionary)**
NASA/CR	Space Shuttle Processing: A Case Study In Artificial Intelligence
NASA/CR 1999-20893	**A User's Manual for Developing Cost Estimator Relationships**
NASA/CR-1998-207656	**The ASAC Carrier Investment Model (3rd Gen)**

3 Conclusions and Recommendations

The problem of estimating the cost of conceptual space projects is not an exact science and demands knowledge of the accuracy of the data and its effects on the final estimate. Even estimates for well-established launch and mission applications have inherent uncertainties due to price fluctuations, parts availability, and change in technology.

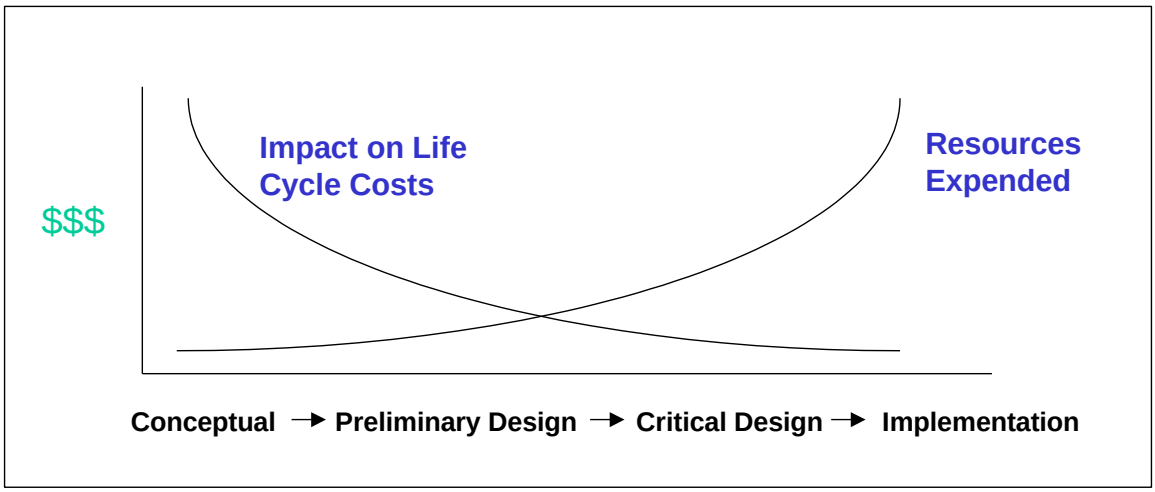

Figure 1. Life Cycle Costs and Resources Expended vs. Project Phase

Compounding the situation, as shown in Figure 1.0, is the desire to affect and set a course for a project during as early a conceptual phase as possible so as not to expend major resources. An appropriate balance of decision making information early in a project contrasts with still being able to redirect those decisions based on cost or flight rate analysis as these evolve. Especially as in many cases resource expenditures rise steadily as a system definition occurs the need is to be able to generate the insight required into future systems costs, such as costs of operations, "a priori" without expending resources to a degree that alternate options and redirections are not possible.

During the data collection phase, the author found existing models utilizing parametric cost models, activity based costing, costs based on analogy and similarity, and unique costing approaches. It appears that activity based costing is the current trend. It may not, however, be appropriate for all cost efforts because it requires (some level of) detailed knowledge of industrial processes. Our more conceptual space projects may not provide such in-depth (if any) knowledge of the processes involved. Parametric modeling, on the other hand, takes a more 'thermodynamic' approach, and determines costing based on more general driving parameters such as size, complexity, and application specific drivers. This approach may be the prime method for areas where process knowledge is scant or non-existent. Similarity- or analogy-based estimates may be well suited for conceptual projects that are similar or scalable from well-known cases. The TRANSCOST model provides a very good framework for organizing conceptual space projects and has a proven track record for historical projects. Its Flight Operations Cost Model is particularly applicable to the Vision Spaceport Cost Model. The above modeling choice predicament has parallels in physics: Detailed quantum-mechanical models do very well predicting atomic and nuclear behavior and many macro-scale phenomena as well. Thermodynamics and statistical mechanics, are also successful predictors of large-scale phenomena such as the behavior of gasses, liquids, and solids on a large scale. Thermodynamic models extract

relatively few key parameters and derive fundamental and useful models of reality. In the nebulous world of conceptual finance, we may need to utilize a rational combination of parametric, activity-based, analogy-based, and unique costing approaches. We, therefore, should consult experts in the field for guidance and enlightenment. Consequently, the author recommends that the VSP Synergy Team consult with:

1. The MITRE Corporation's Economic Decision and Analysis Center (EDAC)
2. Mr. Gideon Samid, of D&G Sciences Corporation
3. The Aerospace Corporation's Costing Experts
4. Edwin Dean, the NASA/Langley Costing/Business Process Expert
5. JSC Engineers that developed the space-related cost models
6. Jan Emblemsvag, Georgia Tech graduate student, author of ABC Model with Uncertainty

A number of COTS cost modeling and process modeling tools are available that might accomplish significant parts of the costing/risk analysis efforts. Consequently, the author recommends the following tools be obtained for evaluation:

Table XVIII, COTS Tools Recommended for Evaluation

Tool Type	Tool Name	Link
Process Modeling	IS/Modeler	http://www.ismodeler.com/index.html
Process Modeling	Simulation Dynamics	http://www.simulationdynamics.com/index.html
Process Modeling	Event & Activity Scheduler	
Activity-Based Costing	NetProphet (ABC)	http://www.sapling.com/
Manufacturing Cost	Costimator	http://www.costimator.com/
Fabrication Cost	FabriCost	http://www.costimator.com/
Risk Assessment	CrytalBall	http://www.decisioneering.com/crystal_ball/index.html
Risk Assessment	@Risk	http://www.palisade.com/
Unique Costing	BiPSA	http://www.dgsciences.com/bipsa/bpsa7n16.htm

The author also recommends that Mr. Bryant Aumack's ATA Systems Code approach be applied to Shuttle cost accounting and tracking. This would effectively transform the previously unique, closed accounting and tracking systems to an open one and open the door to applying (or modifying) existing aircraft cost models and accounting tools for Shuttle purposes. It would also solve the 'lack of data' problem plaguing attempts to reliably mode Shuttle costs.

In light of the impressive hurricane tracking modeling by FSU meteorologists who judiciously combined the outputs of several models, a similar approach, BiPSA, could very well be applied to spaceport costing.

In a similar light such an approach was used by NASA in it's 1997 Highly Reusable Space Transportation System study. Table XVI from the NASA HRST study executive summary highlights the use of multiple tools toward gaining insights supporting complex technology, R&D related, investment decisions.

Table XIX Use of Multiple Estimators and Analysis in Space Transportation Operations

Concept Name	Number of Times Ranked in Top 3 by Analysis
Argus	8
ACRE 183	5
Hyperion	4
KM	3
Waverider	2
ACRE 92	1
TSTO	1
ANSER	0
LACE	0
SSTO(R) LA	0

From the NASA HRST study, Executive Summary, November, 1998; Different tools and experts can be successfully used to contribute to the analysis of complex, long term, future R&D and investment decisions such as those engendered within generic space transportation system design types. The approach is similar in thought to the "Polling Scenario" as discussed further ahead.

Mr. Gideon Samid, inventor of BiPSA, framed our situation very succinctly:

"BiPSA: Binary Polling Scenario Analysis, is a new approach to estimate cost at knowledge-edge. These are estimates, which border on the guessing zone. Such estimates defy the true and tried methods and tools of nominal cost engineering. They are soaked with uncertainty, inundated with 'unknowns' and require a long list of restrictive assumptions (each removes the estimate further from reality) for any estimate to take place. **Just about every spaceship that NASA ever built, was such a knowledge-edge case.** Off shore rigs until today defy construction cost estimators. Software projects, control, electronics, pharmaceutical undertakings -- all characterized by fast evolving technology and the collapse of history as a direct estimating source. How can data from software projects that were written in the 70s in COBOL for the IBM-360, be of any help for a C++ or JAVA project written for an Intranet environment? By way of contrast, the factors that represent, say, the cost of paint in a construction project are not much different today compared to what they were 30 years ago.

The fundamental difficulty, and in fact the metrics for knowledge-edge estimates is the spectrum of learned opinions. While construction estimators would differ by say 5 or 10 percent from each other, (even for a multi million dollar project), estimators of R&D, and high-tech engineering would mark a huge span of opinions and estimates, one perhaps twice or even thrice than the other.

Not only do the estimates differ on their calling, but their agreement or disagreement is often hard to ascertain. Each estimator would prepare his or her own list of assumptions and so construct his estimate. If the assumptions are not the same, there is little point in comparing the estimates themselves. In practical terms, for a large project, the owner would often summon several renowned estimators and instruct each to come up with his or her own estimate. The expert, if only to justify his subsequent bill, would prepare a detailed report, print it out in several copies and distribute it to his client. So do the other say, three of four independent experts. What is the poor owner to do? Where will he find time to even read the over detailed, often pompous narrations, and how would he compare the assumptions the suppositions, the strength of the underlying logic etc.

So with all that investment in independent estimates the result becomes a confusion, and a ripe case for "another study" or for a special committee to look into the apparent complexity.

The above description applies to a grown class of estimates. They are estimates, which fall between the two extremes:

-- formula ready

-- random picking

The formula-ready estimate are those which can be computed with the aid of a proper formula, and the result is quite sound. The random-picking cases are those where there is so little knowledge, so little information that it is impossible to claim any scientific basis to an asserted opinion. It's every body's guess!

It so happens that some of those hard to estimate projects turn out to be the most profitable projects for their investors. The problem is that these gems hide inside a heap of look-alike. It is no secret that prosperity tomorrow depends on innovation today. And so visionaries, dare-devils, as well as arch-conservatives like major banks take their chances, and in turn challenge us, cost engineers, with developing new methods, novel concepts, for taking on this impossible estimates. BiPSA: Binary Polling Scenario Analysis is an attempt to respond to the challenge."

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